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Eco-friendly control of *Thrips tabaci* in garlic with a mixture of *Beauveria bassiana* and potassium silicate

Abstract – The objective of this work was to evaluate a mixture of the entomopathogenic fungus *Beauveria bassiana* and potassium silicate – a plant-resistance inducer – for thrips management. Three-year field experiments (2017-2019) were carried out using the Ito garlic cultivar, from 25−100 days after germination, with adults of *Thrips tabaci* monitored fortnightly via sticky traps. Temperature, humidity, wind speed, and planted area were correlated with thrips populations. Treatments including *B. bassiana*, potassium silicate, chlorfenapyr, and a mixture of the fungus and silicate delayed thrips population peaks, in comparison with the controls. The fungus-silicate mixture outperformed chlorfenapyr and individual treatments in 2019, maintaining thrips populations below the control threshold of 20 thrips per plant. The number of thrips varied between years and treatments, and the population dynamics did not correlate solely with the planted area. The fungus-silicate mixture is a promising, sustainable approach for *T. tabaci* management in garlic cultivation, offering an alternative for biopesticide development and integrated pest management strategies.

Index terms: *Allium sativum*, *Thrips tabaci*, biological control, entomopathogenic fungi, silicon, integrated pest management.

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Controle ecológico de *Thrips tabaci* com uso de alho e mistura de *Beauveria bassiana* com silicato de potássio

Resumo – O objetivo deste estudo foi avaliar uma mistura do fungo entomopatogênico *Beauveria bassiana* e silicato de potássio – um indutor de resistência em plantas – para o manejo de tripes. Experimentos em campo por três anos (2017-2019) foram conduzidos em cultivo da cultivar de alho Ito, de 25 a 100 dias após a germinação, com adultos de *Thrips tabaci* monitorados quinzenalmente por meio de armadilhas adesivas. Temperatura, umidade, velocidade do vento e área plantada foram correlacionadas com as populações de tripes. Tratamentos com *B. bassiana*, silicato de potássio, clorfenapir e uma mistura do fungo e silicato retardaram os picos populacionais de tripes, em comparação aos controles. A mistura fungo-silicato superou o clorfenapir e os tratamentos individuais em 2019, mantendo as populações de tripes abaixo do limiar de controle de 20 tripes por planta. O número de tripes variou entre anos e tratamentos, e a dinâmica populacional não se correlacionou exclusivamente com a área plantada. A mistura fungo-silicato é uma abordagem sustentável promissora para o manejo de *T. tabaci* no cultivo de alho e é, também, uma alternativa para o desenvolvimento de biopesticidas e estratégias de manejo integrado de pragas.

Termos de indexação: *Allium sativum*, *Thrips tabaci*, controle biológico, fungos entomopatogênicos, silício, manejo integrado de pragas.

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Introduction

Virus-transmitting insects are the main reason for yield losses in commercial garlic areas, reducing the bulb seed quality and market value (Akhter et al., 2019). Garlic production costs have increased significantly due to insect pest occurrence, with economic losses reaching millions of dollars annually in Brazil (Oliveira et al., 2014). *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) is a key pest in garlic and onion, causing direct and indirect damage, regardless of the type and genotype cultivated (Gill et al., 2015; Ferreira et al., 2017). These insects remain between the sheaths of central leaves, which are tenderer and have a smaller leaf angle than outer leaves (Mo et al., 2008). This sheltered location naturally provides ecological advantages, allowing thrips populations to build up rapidly from early plant development through harvest.

Broad-spectrum pesticides are the most common control method against *T. tabaci* (Gill et al., 2015). However, *T. tabaci* populations shoe low diversity, due to their thelytokous reproduction, which facilitates the evolution of insecticide resistance (Li et al., 2015, 2020). Induced-genetic resistance cases from insecticide usage have been reported with 112 records for *T. tabaci* populations worldwide (Arthropod Pesticide Resistance Database, 2020). Additionally, insecticides recommended by the Brazilian Ministry of Agriculture, such as chlorfenapyr (of a chemical group analogous to pyrazole), may also reduce populations of natural enemies (Barros et al., 2015) and be toxic to pollinators (Costa et al., 2014). Therefore, searching for more sustainable methods according to integrated pest management (IPM) practices is necessary.

Microbial control agents, such as *Beauveria bassiana* (Bals.) Vuill., offer eco-friendly alternatives for suppressing thrips populations in greenhouses and field conditions (McGuire & Northfield, 2020). The leaf architecture of garlic and onion plants may protect the fungus against UV rays (Kaiser et al., 2019), which is one of the main constraints to its viability. The maintenance of adequate air humidity by pivot irrigations, commonly used in garlic production in Brazil, favors the fungal biological activity by maintaining a humid environment (Mishra et al., 2014). Under these conditions, fungal colonization may perpetuate horizontally in the field, among living or infected insects, including cadavers (Conceschi et al., 2016). However, the effectiveness of microbial pest control in open fields has been debated, mainly due to reduced viability after foliar sprays are exposed to sunlight. The use of oils or molasses as additives and protectants for conidial spores in tank mixes have been recommended, but their actual efficacy remains contested (Fernandes et al., 2015; Gandini et al., 2020).

Synergism between silicate-based products and entomopathogenic fungi has been reported, involving interactions such as breaking lipid barriers of the host cuticle, which facilitates fungal penetration and colonization. The mixture of *B. bassiana* and potassium silicate (K_2SiO_3) increased the mortality of *Tetranychus urticae* (Koch) (Tetranychidae) (Gatarayiha et al., 2010). Silicate compounds alone may provide advantages in plant protection, by acting through polymerization in superficial layers of plant tissues, which has been suggested as a preliminary mechanical defensive strategy against biotic plant stressors, such as pathogens (Oliveira et al., 2019) and insects (Alhousari & Greger, 2018).

Silicate-based compounds may increase the persistence and virulence of entomopathogenic fungi after foliar applications, potentially increasing their efficacy against thrips. This fact should be better evaluated on garlic (*Allium sativum*) plants.

The objective of the present work was to evaluate the efficacy of the mixture between *B. bassiana* and potassium silicate to control *T. tabaci*.

Materials and Methods

The study was carried out in the municipality of Campo Alegre de Goiás (17°36'22.8"S, 47°46'36.5"W), in the state of Goiás, Brazil. Ito garlic (*A. sativum*) seed bulbs – classified as "noble" in the Brazilian group of garlic cultivars – were purchased from certified nurseries in the municipality of Curitibanos, in Santa Catarina state, Brazil. These seed bulbs were stored in a cold chamber between 2ºC and 4°C, with relative humidity from 50% to 60% for 55 days through vernalization. This process is necessary for the seed bulbs to reach GSI (germination speed index) above 70% (Marodin et al., 2019). Climatic data, such as temperature, relative humidity, and wind speed were recorded during the experiment, using an automated weather station installed at the experimental site. Garlic was cultivated in a field, in total areas as follows: 120 ha in 2017, 110 ha in 2018, and 150 ha in 2019.

Treatments were arranged in a randomized complete block design with four blocks and four replicates. Each experimental plot had four double rows of 30 cm between the double lines, 10 cm between single rows, and 10 cm between plants, totaling 160 plants per plot (4 double rows × 20 plants per row × 2 rows). Beds were of 5 m length and 2 m width. A 2 m border was used between adjacent plots. The experimental blocks were spaced 3 m apart. Three consecutive growing seasons (2017, 2018, and 2019) were evaluated from the 25th day after bulb germination (DAG) until the 100t^{h} DAG.

Four treatments (T1 to T4) and one control (T5) were performed as follows: T1, *Beauveria bassiana*; T2, potassium silicate; T3, chlorfenapyr; and T4, *B. bassiana* plus potassium silicate mixture; and T5, the control that consisted of water-only sprays.

The source *B. bassiana* was the commercial product BeauveControl (Simbiose Agro, Cruz Alta, RS, Brazil), based on the isolate IBCB 66 (2×10^8 CFU g^{-1}) in wettable powder formulation applied at 2.5 g L^{-1} water. The potassium silicate source contained 12% silicon (Si) and 15% potassium (K_2O) (Solo Fértil SP Comercial Agrícola Ltda., São José do Rio Preto, SP, Brazil), applied at 0.4 L 100 L^{-1} of water according to manufacturer recommendations. Chlorfenapyr is an insecticide-acaricide from the pyrazole analogue group (BASF SE, São Paulo, SP, Brazil), in concentrated suspension formulation with 240 g L^{-1} a.i., applied at 80 mL 100 L^{-1} water.

All treatments were applied using a CO_2 sprayer (25 L) with 2 m side bar with four conical spray tips (M 054), under 241 kPa pressure. The spray volume was 200 L ha^{-1} for *B. bassiana* treatments, and 1000 L ha^{-1} for chlorfenapyr, according to technical recommendations. Fortnightly applications were made from the 25th to the 100th DAG per experimental unit, at the end of the day around 17:00 h.

Thrips were surveyed using yellow sticky traps (15 cm long, and 10 cm wide) positioned immediately above the upper third of garlic leaves. One sticky trap was installed per experimental unit. According to this sampling method, only adult thrips were considered. Trap height was periodically adjusted, and traps were replaced fortnightly after spray applications. The number of *T. tabaci* adults were counted per trap, generating estimated values of thrips per plant.

Prior to the analysis, descriptive statistics were conducted, and data were examined for potential sources of problems including outliers, extreme values, and distribution patterns. The total number of sampled thrips per year was subjected to the Pearson's correlation (Kozak et al., 2012) with temperature, relative humidity, wind speed, and total area cultivated with garlic.

The discrete data were initially subjected to the analysis of variance for a randomized complete block design. Prior to the analysis of variance, the assumptions of normality, homoscedasticity, and independence of residuals were verified, using the tests by Shapiro-Wilk, Levene, and Durbin-Watson, respectively, at 5% probability. The linearity assumption for GLM procedures was verified through residual plots and scatter plots of predicted versus observed values. Normality and homoscedasticity assumptions were not fully met, and data transformation was required. The counts of thrips were based on data transformed to log (x + 1), to achieve normality and homoscedasticity of residuals, as count data typically follow a Poisson distribution with increasing variance as the mean increases. Means were separated by the Duncan's multiple amplitude test, at 5% probability, using the GLM procedure of SAS (SAS Institute Inc., Cary, North Carolina, USA).

A two-way analysis of variance (PROC GLM) was performed considering years and treatments as factors, in order to assess possible differences for the number of thrips per plant and to evaluate treatment stability through years. The relationship between the number of thrips per plant (dependent variable), and days after germination and treatments (independent variables), was subjected to regression analysis. Prior to the regression analysis, the multicollinearity among independent variables was assessed using variance inflation factors (VIF < 10). Residual distribution was checked through normal probability plots, residual versus fitted plots, and Kolmogorov-Smirnov's tests, to validate the parametric assumptions.

Results and Discussion

The number of thrips per plant was lower in treatments with chlorfenapyr and the mixture of *B. bassiana* and potassium silicate in 2017 and 2018. However, in 2019, this parameter was lower

in treatments with the fungus-silicate mixture only (Figure 1).

The fungus-silicate mixture was the only treatment that maintained *T. tabaci* population levels below the Brazilian control threshold (20 thrips per plant) over three consecutive years. Higher numbers of thrips resulted from *Beauveria bassiana* only (T1) and potassium silicate only (T2) treatments than from the more effective treatments (with sole chlorfenapyr (T3) and from the fungus-silicate mixture (T4); however, both T1 and T2 treatments caused the reduction of the thrips population, in comparison with the water-only control (Figure 1). In 2018 and 2019, the mean (standard error) of thrips numbers in the control treatment were 19.89 (1.90) and 20.99 (2.50) thrips per plant, respectively. They were higher than the counting in 2017, which was 16.86 (2.00) thrips per plant.

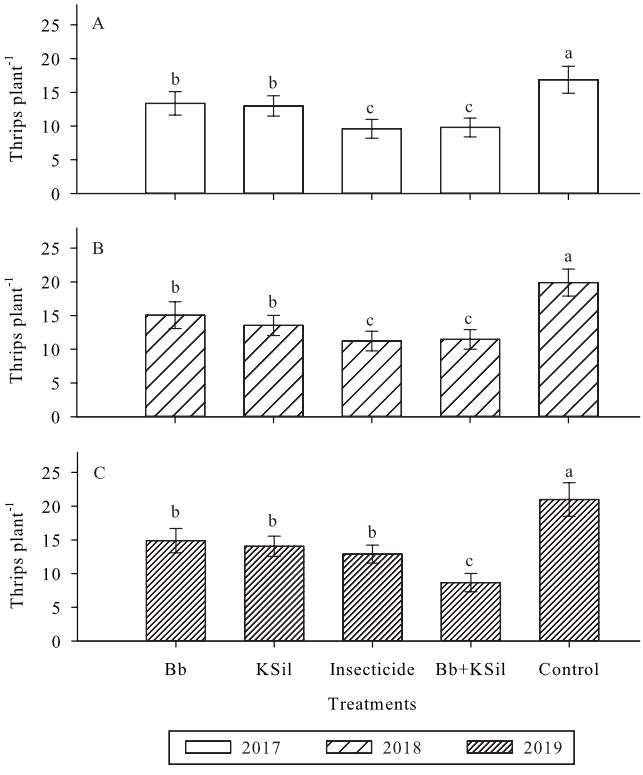

Figure 1. Number of thrips (*Thrips tabaci*) per plant of the Ito garlic cultivar (mean ± SE), in the growing seasons of 2017 (A), 2018 (B), and 2019 (C), for each treatment: *Beauveria bassiana* (Bb); potassium silicate (KSil); clorphenapyr (Insecticide); fungus-silicate mixture (Bb + KSil); and water (control). Means followed by equal letters, per year, do not differ by the Duncan's test, at 5% probability.

Thrips population variations fitted the polynomial cubic regression models for the *B. bassiana*, potassium silicate, chlorfenapyr, and fungus-silicate mixture treatments. Thrips numbers decreased at the 40th DAG, followed by an immediate increase from the 55th DAG. Peaks of *T. tabaci* populations occurred between the 70th and the 85th DAG, with subsequent decline between the 85th and the 100th DAG (Figure 2). At the 100th DAG in the fungus-silicate mixture treatment, the thrips numbers approached zero in 2017, 2018, and 2019, with 0.62 (0.17), 0.88 (0.24), and 0.22 (0.05) thrips per plant, respectively.

Conversely, thrips numbers in the water-only control fitted the quadratic regression models across all three years. The control treatment showed rapid population increases from the 25th to the 70th DAG, when maximum peaks occurred, followed by sharp declines between the 85th and the 100th DAG. At the end of the experiment period (at the 100th DAG), the thrips numbers in the control increased with each agricultural year: 8.64 (1.43), 12.16 (2.02), and 20.28 (3.37) thrips per plant in 2017, 2018, and 2019, respectively.

Temperature, relative humidity, and wind speed increased across agricultural years (Table 1). Total *T. tabaci* numbers differed among years, with lower values in 2017 than in 2018 and 2019 (Table 1). Total thrips numbers correlated positively with climatic parameters (temperature, relative humidity, and wind speed) but not with total planted area (Table 2).

The increase of about 30% in thrips numbers during 2018 and 2019, in comparison with those in 2017, relates to higher temperatures in later years. Thripidae species in tropical areas prefer temperatures between 20-25°C, and the combination of higher temperatures with increased relative humidity and wind speeds in 2018 and 2019 likely favored *T. tabaci* population increases (Morsello et al., 2008).

The enhanced efficacy of the fungus-silicate mixture can be attributed to both physiological effects on plants and physical effects on insect cuticles. Silicon polymerization in superficial layers of plant tissues serves as a first defense mechanism against pathogenic fungi (Oliveira et al., 2019), and lignification of these silicate polymers constitutes a physical barrier against sucking and chewing insects (Alhousari & Greger, 2018). Simultaneously, potassium silicate likely provided protection against fungal conidia dehydration, increasing persistence under UV exposure, as reported

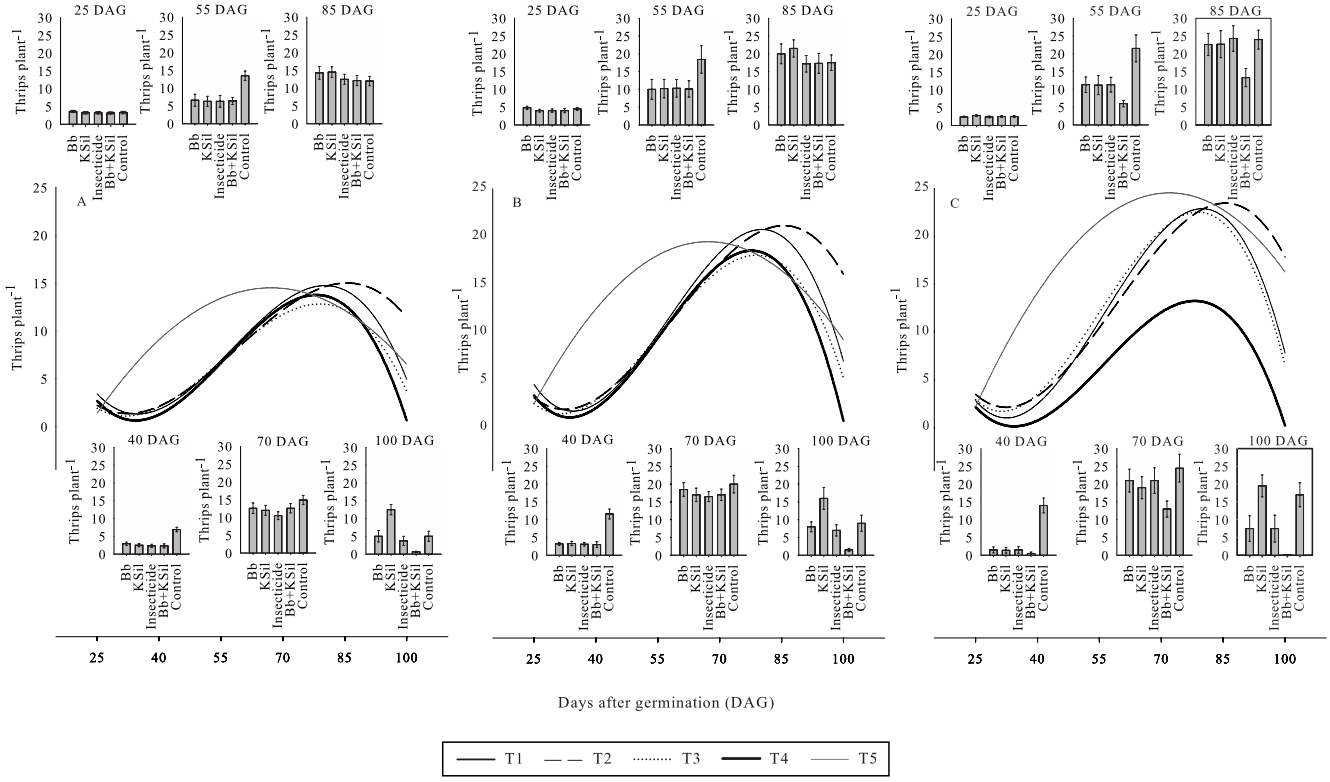

Figure 2. Number of trips (*Thrips tabaci*) at 25, 40, 55, 70, 85, and 100 days after the germination (DAG) per plant of the Ito garlic cultivar (mean ± SE) subjected to foliar spray with the following treatments: *Beauveria bassiana* (T1); potassium silicate (T2); chlorfenapyr (T3); fungus-silicate mixture (T4); and water (T5). Growing seasons: A, 2017; B, 2018; and C, 2019. Means followed by equal letters, in the same year, do not differ by the Duncan's test, at 5% probability.

Table 1. Mean values of temperature, relative humidity (RU), wind speed (Wind), total planted area (Area) with the Ito garlic cultivar, and total number of *Thrips tabaci* sampled (Tt).

Year	Temperature (°C)	RU (%)	Wind (m s^{-1})	Area (ha)	Tt
2017	18.5	56.5	2.5	120	5,187
2018	20.5	61.5	3.8	110	7,095
2019	22	63.5	4.9	150	7,351

Table 2. Correlations between temperature, air relative humidity (RU), wind speed (Wind), the Ito garlic cultivar planted area (Area), and the total number of sampled *Thrips tabaci* (Tt).

	Temperature (°C)	RU (%)	Wind speed (m s^{-1})	Area (ha)	Tt
Temperature	1.0	-	-	-	-
RU	0.987*	1.0	-	-	-
Wind	0.973*	0.991*	1.0	-	-
Area	0.661*	0.533*	0.686*	1.0	-
Tt	0.933*	0.999*	0.920*	0.355^{ns}	1.0

*Significant at 5% probability by the Pearson's test. ^{ns}Nonsignificant.

in other studies (Bell & Hamalle, 1974; Gatarayiha et al., 2010; Kim et al., 2014).

The fungus-silicate mixture showed mean reductions of 74%, in comparison with the control, between the 40th and the 55th DAG over three years, while *B. bassiana* (T1), potassium silicate (T2), and chlorfenapyr (T3) treatments showed reductions of 32%, 49%, and 59%, respectively. These results represent a mean gain of 42% for the control efficacy when combining the fungus with silicate, in comparison with the treatment using *B. bassiana* only, and 15% improvement over the treatment with chlorfenapyr only.

Lower thrips numbers in the treatment with the fungus-silicate mixture compared to that with chlorfenapyr, in 2019, may indicate insecticide resistance development. Chlorfenapyr-based insecticides have been associated with resistance in *Frankliniella occidentalis* (Gao et al., 2012). The continued effectiveness of the biological mixture while insecticide efficacy declined supports the potential for sustainable pest management.

The fortnightly application schedule may have enhanced *B. bassiana* efficacy through increased fungal conidia density and horizontal transmission among infected insects (Lacey et al., 2015). The fungus-silicate mixture achieved thrips numbers about half the Brazilian control threshold, suggesting potential for integrated pest management applications.

Conclusions

1. The dual-action mechanism of biological control and induced plant resistance addresses current limitations for thrips (*Thrips tabaci*) management in garlic (*Allium sativum*) production.

2. The performance of the fungus (*Beauveria bassiana*)-silicate mixture under different environmental conditions and thrips population pressures indicates potential of this treatment for reliable integration into pest management programs.

3. The mixture establishes a framework for developing next-generation biopesticide formulations that could optimize fungal survival under field conditions.

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No generative artificial intelligence (AI) was used in this study.

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The authors declare no conflicts of interest.

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